1.0 A Pilot Study of Experimental Demonstration of Cooling of Ions by a Bunched Electron Beam (2015-LDRD-01a)

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Project Status

Preparations of this experimental demonstration have been carried out both at IMP, China and at JLab. The work at IMP is not a part of this LDRD, however, since it is closely related, I include a short summary here too. The JLab LDRD work, though with a late start due to commitments to MEIC and LDRD 1507, has made progress in cooling simulations for a test case and in evaluation of the required diagnostic capability for supporting the experiment.

At IMP, a new 35 kV high voltage platform was purchased from a European manufacturer and is expected to be delivered in 12 weeks. On the top of this platform, a RF modulator is being built to modulate emission of electrons from a thermionic cathode to form a (long) bunched electron beam for the DC cooler in the CSRm ring. Specifically, when a weak modulation voltage relative to the DC bias voltage is applied to the electron gun, the electrons may not leave the cathode or may be pushed back to the cathode if the phase is not right. The amplification factor of this high voltage pulse system is seven, and its frequency is 2.8 MHz, which is approximately 10 times of the revolution frequency of a $^{12}C^{6+}$ ion beam in the CSRm ring. The average current of the modulated electron beam is a few tens mA, and energy is 4 keV. Frequency tuning capability is nevertheless very limited. The equipment will be installed in the CSRm cooler and commissioned in August 2015, the scheduled machine down time.

A preliminary parameter set for the proposed cooling experiment can be developed based on this modulated electron beam. The selected ion species is fully stripped carbon ($^{12}C^{6+}$), its energy is very low (8 MeV/u) thus the electron cooling effect should be very strong even with modest electron beam current. This ion beam inside the CSRm ring can be either coasting or bunched by a RF system of 0.7 MHz. The following table summarizes the main parameters. If the bunch repetition frequency of the electron beam is locked to exactly an integer times the revolution frequency of the ion beam in the CSRm ring, there should be weak bunching effect on the ion beam in the longitudinal direction.

Table 1: Main parameters for the bunched beam electron cooling demo at IMP

$^{12}C^{6+}$	Kinetic energy	7 / 30	MeV/u
	Geometric emittance x/y	5 / 5	μm·rad
	dp/p	4	10^{-4}
	Number of particles	5	10^{8}
e^-	Kinetic energy	3.8 / 16.5	keV
	Radius	2.5	cm
	Average current	30 - 70	mA
	Temperature x/y	0.05 / 0.1	eV

The experiments can be performed at two energies: 7 MeV/u, the injection energy of the CSRm ring, and 30 MeV/u. The corresponding electron energy is 3.8 and 16.5 keV respectively. The average current of the electron beam ranges from 30 mA to 70 mA. Other related parameters are listed in table 1. The cooling processes have been simulated using BETACOOL for both ion energies and current of the electrons are 30 mA and 70 mA. The emittance evolutions are shown in Figure 1. In the simulations, the bunched electron beam is modeled as a DC beam with equivalent current, so the results should be interpreted as an average effect of cooling by a bunched beam. This approximation should be valid when the bunch lengths are long. In all four cases shown in Figure 1, the cooling effect is distinct. Significant reduction of the emittance or momentum spread can be achieved within two minutes.

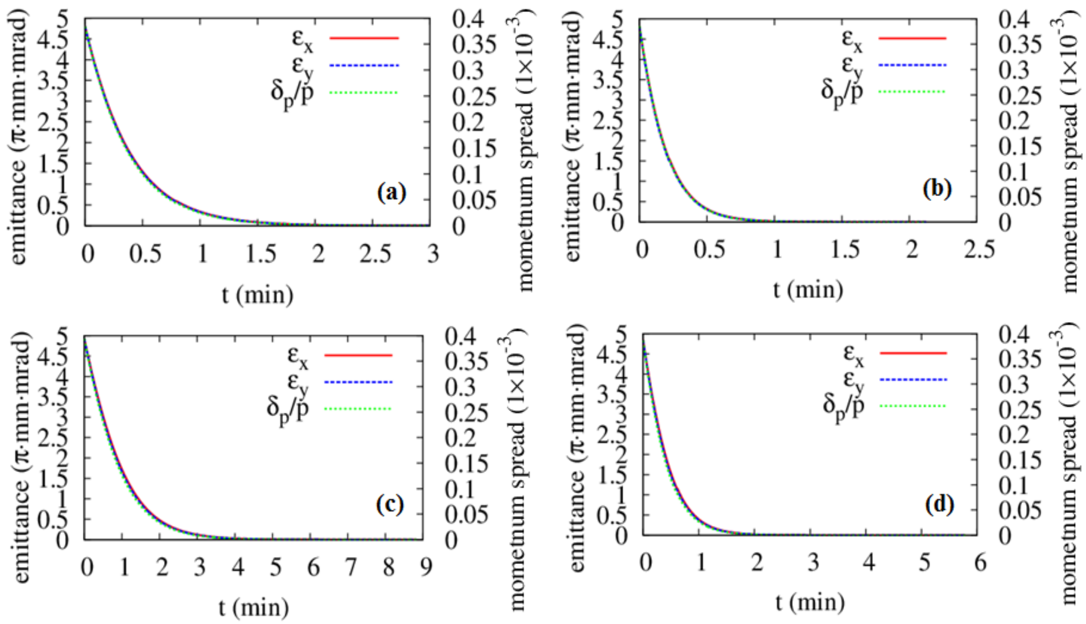

Figure 1 Evolution of emittance of a $^{12}C^{6+}$ beam under electron cooling with different ion energies and electron beam average current: (a) KE_c = 7 MeV/u, I_e = 30 mA, (b) KE_c = 7 MeV/u, I_e = 70 mA, (c) KE_c = 30 MeV/u, I_e = 30 mA, (d) KE_c = 30 MeV/u, I_e = 70 mA.

Presently, the IMP CSRm ring has very limited capability in diagnostics for both ion beam and cooling electron beam. There are only two BPMs (beam position monitors) located near both ends of the cooling solenoid, however, there is no BCM (beam current monitors) nor capability to measure longitudinal density profile. The longitudinal cooling efficiency is determined by measuring the momentum spread of the ion beam.

For the bunched beam cooling experiment, it is essential to characterize the cooling electron beam including beam average current (thus bunch charge through bunch repetition rate) and bunch length. We are exploring feasibility to make modification of these two BPMs so they can also be used for beam current measurement. The preliminary finding is that, without dismounting current pickup hardware, the pickup circuit can be modified externally for BCM measurement. Such modifications will be on both connections to one or two chosen inductors on each pairs of capacitive electrodes and the data processing in the beam diagnostic instrument and software. The technical challenge is on the circuit itself to convert the transmission-line type pickups to a resonance type pickup circuits. The resonance frequency has to match the modulation frequencies of electron beam and ion beam since the BPM location is for measuring both electron and ion beam positions. Two resonator circuits have to match two modulation frequencies, one for electrons, one for ions. To complete this study, additional technical information about IMP BPM is required. This has already been communicated to the IMP colleagues

Project Plan

It seems that the collaborators at IMP in China have been focused primarily on procurement, installation and evaluation of a high voltage RF power source. Procurement of a second power source has also been planned. However, a detailed experiment plan has not yet been developed at IMP. There are also indications that the experiment could happen as early as this summer.

Under the circumstances, the short term (next two months) priority of this LDRD is to take a leading role in development of a test plan which must have sufficient technical details including planned measurements, parameter tune-able range and knobs, and diagnostics capabilities. Discussion of various failure mechanisms must be conducted as well with colleagues from IMP and Budker Institute, and potential mitigation options should be identified. The deliverable is a technical document.

Simulations will be the primary activities for the remaining period of this LDRD. There are some modest code developments for expanding the capability of the existing BETACOOL and the work is expected to be completed in two months. Then the simulation work will follow.

A JLab RF technology expert, Haipeng Wang, is helping to evaluate the beam diagnostic issues for this experiment. He has over 14 year experience (including 9 years in BNL) on DC high voltage platform and power supply, and associated high current gun, before join JLab and going to SRF area. He has contributed technical information to this mid-year report. Haipeng will visit IHEP, China in June of this year for consulting the HOM damping design study for CepC, a circular e+e- collider as a Higgs factory. We are making a plan for him to have a short visit to IMP during his time in China to inspect the new cooler power source stand, the CSRm beam diagnostic capabilities and preparation of the cooling experiment.

If the IMP storage ring beam time is allocated in this summary and the high power source stand is constructed and tested successfully, JLab should send a delegate group to participate in this proof-of-principle experiment. Identifying members of this delegation must include consideration of the members' expertise, complements with IMP expertise, and JLab own electron cooling long-term development plan as well. If this happens, it should be considered as a re-plan of this LDRD.

Budget

Publications

No.

Workshops/Conferences

No.